Large, Monolithic, Weighing Lysimeters[1]

Arland D. Schneider and Terry A. Howell[2]
Member ASCE Member ASCE

Abstract

Monolithic lysimeters preserve existing vegetation and soil properties that can be destroyed by excavation and filling. Site preparation for constructing large, monolithic lysimeters includes operations such as wetting or drying the soil, preserving vegetation, preventing soil compaction and installing anchors for pulldown operations. Large soil monoliths are collected by coring from the top, by encasing soil blocks from the side and by compositing smaller soil monoliths within a soil tank. Soil monoliths can be under-cut with steel plates that later become the soil tank bottom, or they can be lifted and overturned for installation of the tank bottom. Enclosure tanks for monolithic lysimeters are preferably installed with minimum excavation to eliminate large areas of disturbed soil around the lysimeter.

Introduction

Monolithic lysimeters, first used by Lawes et al. (1881), are required if excavation and backfilling cause major changes in soil physical or chemical properties. Such changes are most likely to occur in rocky, layered or highly structured soils. For example, the monolithic, weighing lysimeters at Coshocton, OH (Harrold and Dreibelbis, 1951) penetrate fractured rock which could not be reconstructed after excavation. The Bushland, TX lysimeters are located in clay loam soil with a dense, slowly-permeable subsoil and a calcic horizon at a depth of 1.4 m (Marek et al., 1988). This soil limits water movement and plant rooting, and major differences in plant growth can

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[1]Contribution from the USDA-ARS, Southern Plains Area, Conservation and Production Research Laboratory, Bushland, TX.

[2]Agricultural Engineers, USDA-ARS, P. O. Drawer 10 Bushland, TX 79012.

occur on modified soils (Eck and Taylor, 1969 and Schneider and Mathers, 1970). Aboukhaled et al. (1982) discuss the difficulty of isolating and enclosing a large soil mass and the need for specialized techniques, equipment and labor.

Monolithic lysimeters are also desirable for studying evapotranspiration from existing grassland or forest vegetation. To preserve delicate prairie grassland for evapotranspiration measurements, Armijo et al. (1972) used a coring technique to collect a 3.05-m diameter by 1.2-m deep monolith. Reyenga et al. (1988) used an encasement procedure to place eucalypt forest vegetation in a weighing lysimeter for evapotranspiration research. Fritschen et al. (1973) cored a 3.7-m diameter monolith containing a 28-m Douglas-fir tree. Table 1 lists information for ten large, weighing, monolithic lysimeters in Australia, Canada and the United States.

This paper is a review of procedures for collecting large monoliths and of special requirements for constructing monolithic lysimeters for evapotranspiration measurements. Procedures for coring or encasing and for undercutting and overturning monoliths with a surface area larger than 2 m^2 are described.

Monolith Design

The desired lysimeter shape, area and depth for accurate evapotranspiration measurements (Howell et al., 1991) and the feasibility of collecting a large soil monolith need to be considered in the lysimeter design. Soil type can affect the difficulty and even the feasibility of collecting a large soil monolith. Rocky soils restrict the use of coring and severely limit the ability to cut smooth walls for encasing a soil block. Sandy, unstructured soils may be difficult to encase. These soils can only be undercut with a continuous steel plate because the granular material will fall between pipes or rods driven under the monolith. Construction materials are also an important consideration in collecting large soil monoliths for use in weighing lysimeters. Most soil tanks have thin steel or fiberglass walls with a small wall and air gap area in comparison to the surface area of the monolith. Enclosure tanks are usually made of concrete or steel, but with concrete tanks, the upper 0.3 m or more of the walls around the soil tank needs to be steel to minimize the wall area at the surface.

Dimensions of large monoliths for weighing lysimeters are often a compromise between local soil and crop conditions and the variables affecting the accuracy of evapotranspiration measurements. Accuracy is directly proportional to the surface area of the monolith and the accuracy of the scale system and inversely proportional to the mass

Table 1. Ten large, monolithic, weighing lysimeters and some of their characteristics.

Location and Reference	Area m^2	Depth m	Mass Mg	Soil Type	Collect. Method	Vegetation Preserved
Cochocton, OH Harrold & Dreibelbis (1951)	8.1	2.1	59.0	Silt Loam Over Rock	Coring	Grass
Woodbridge, Toronto, Ont. CA Mukammal et al. (1971)	6.1	0.94	- -	Clay	Compos-iting	Grass
Dover, CO Armijo et al. (1972)	7.3	1.2	22.7	Tight Uniform Silt	Coring	Prairie Grass
Seattle,WA Fritschen et al. (1973)	10.8	1.2	28.9	Gravelly Loamy Sand	Coring	Douglas Fir Tree
Tucson, AZ Sammis (1981)	12.6	1.0	27.3	Fine Gravelly Sandy Loam	Coring	Creosote Bush
Temple, TX Dugas et al. (1985)	3.0	2.7	16.4	Clay	Coring	None
Bushland, TX Marek et al. (1988)	9.0	2.3	45.0	Clay Loam	Coring	None
New South Wales AUST. Reyenga et al. (1988)	10.8	1.5	36.0	Topsoil Over Massive Clay	Encasing	Regenerat-ing Eucalypt
Tennessee von Bernuth (1991)	4.0	1.8	13.7	Sandy Clay	Coring	None
Richland, WA Gee et al. (1991)	2.25	1.7	6.0	Silty Loam	Coring	Sagebrush and Bunchgrass

of the monolith. Although a large monolith surface area is desirable, the size may be limited by cost, monolith collection methods and available construction equipment. The mass of a monolith can be reduced by reducing the depth, but some minimum soil depth is required for plant rooting and development of a normal water-potential profile even with suction drainage.

Collection of Large Monoliths

Methods. Large soil monoliths are collected by coring by encasing or by compositing several smaller monoliths. With the coring technique, the monolith is cut to shape by pressing a bottomless steel tank with a cutting edge into the soil similar to collecting small cores for laboratory testing. Soil can be excavated from around the soil tank as it is pressed down, or a soil block slightly larger than the monolith can be cut and shaped before coring starts. Encasing is a procedure in which the monolith is first cut to shape and then enclosed from the side with sections of the soil tank. Composite monoliths are obtained by cutting smaller blocks of undisturbed soil and fitting them snugly inside the soil tank. A composite is not a true monolilth, but many soil properties and small vegetation can be preserved with the technique.

Site Selection and Preparation. Careful site selection and preparation are necessary to obtain a representative soil monolith. Small diameter soil cores can be collected to locate representative sites for the desired soil. More detailed coring can then be conducted or trenches can be dug to more carefully investigate soil properties and verify the desirability of the chosen site.

Site preparation varies with the method to be used in collecting the soil monolith. For coring, wetting the area to reduce the soil shear strength may be desirable. Plow pans and shallow hard pans can be broken up by plowing or chiseling. Anchors can also be installed for using a pulldown procedure for forcing the soil tank into the ground. If soil water is excessive, vegetation can be used to reduce the soil water content. For the encasing and compositing methods, a thick cover of grass or similar vegetation may be desirable. The vegetation protects the soil surface, and a dense rooting system holds the soil together while the monolith walls are cut to shape. If the lysimeter is to be located at the monolith collection site, control of vehicular traffic is important. Reyenga et al. (1988) protected existing eucalypt vegetation, covered the soil near the excavation site and placed steel mesh over traffic areas. During installation of the Bushland lysimeters, traffic was restricted to roadways around the lysimeters, but compaction from the heavy mobile cranes affected grain sorghum growth during the first cropping year even following extensive tillage.

Coring Procedure. Many methods have been used to force soil tanks into the soil for obtaining soil monoliths. Dead weights are frequently used to develop the required force for pressing monolith tanks into the soil (Harrold and Dreibelbis, 1951; Tackett et al., 1965; Dugas et al., 1985). With the simplest procedure, weights are placed on the monolith tank, and soil outside the tank is excavated until the tank is forced to the desired depth. Although this procedure is effective, downward movement can be erratic, and vertical alignment is difficult. Tackett et al. (1965) controlled downward movement and vertical alignment by gradually placing steel weights on monolith containers with two forklifts and maintaining alignment with the forklifts. Other researchers have trimmed a soil block to nearly the size of the finished monolith before pressing down the soil tank (Bhardwaj and Sastry, 1979; Brown et al., 1974; Fritschen et al., 1973; and Gee et al., 1991). Although more labor intensive, this greatly reduces the required downward force.

Pulldown procedures using hydraulic equipment provide larger pulldown forces than are practical with weights, and vertical alignment and downward control is easier to maintain. Belford (1979) used earth anchors and a 10-Mg hydraulic ram to collect 0.788-m diameter by 1.350-m deep cores in both sandy loam and clay soils. Meyer et al. (1985) modified this procedure by using concrete anchors in which the concrete was placed inside a cavity formed by detonating an explosive. More recently, Schneider et al. (1988) used concrete anchors and more precise hydraulic equipment to collect 3-m square by 2.3-m deep monoliths from a clay loam soil. They also used similar equipment to press 0.75-m x 1.0-m x 2.3-m deep monolith containers into the soil without excavating around the outside (Schneider et al., 1989).

<u>Encasing Procedure.</u> Encasing soil blocks for monolithic lysimeters is a technique especially useful if the soil monolith is to contain existing tall vegetation. Reyenga et al. (1988) encased a 3.7 m diameter by 1.5 m deep soil block supporting regenerating eucalypt forest. After rough shaping with a backhoe, they used an electric spade to trim the soil block to fit a circular template. Corrugated iron sections, 0.6 m high and spanning one-third of the diameter, were placed around the trimmed soil block. The seams were then rivetted and sealed, and the soil-iron interface was sealed with a sand-cement slurry.

<u>Undercutting Procedure.</u> After a soil monolith is enclosed from the sides, the monolith must be undercut for placement of a permanent bottom. Reyenga et al. (1988) used hydraulic jacks to drive steel plates with a sharpened leading edge under an encased monolith. After each plate was fully driven in, another plate was welded on to extend the bottom. Fritschen et al. (1973) used 50-mm x 150-mm rectangular tubing with 4.8-mm wall thickness in the same way that Reyenga et al. (1988) used the steel plates. After the bottom was jacked in place, they trimmed it to shape and welded it to the soil tank. Undercutting with plates is best used in soils without gravel or rock.

Fritschen et al. (1973), for example, found it necessary to undermine the bottom plate and remove rocks from in front of the cutting edge.

In structured soils, monoliths can be undercut by forcing rods or pipes under the tank and then lifting and overturning the monolith. Dugas et al. (1985) forced 12.7-mm diameter steel bars under a 1.5-m wide soil monolith to assist in breaking the soil evenly when the monolith was lifted and overturned. Similarly, Brown et al. (1974) drove angle iron under their cored monoliths with a hydraulic ram and then connected the angles to the soil tank before lifting and overturning. The 3-m square monoliths for the Bushland lysimeters were undercut by boring eight 105-mm diameter openings beneath the soil tank with a pneumatic boring tool (Schneider et al., 1988). Sections of 75-mm steel pipe were welded together as they were inserted into the boreholes. Finally, all the pipes were connected to the soil tank before the monolith was lifted and overturned.

Lifting and Overturning Monoliths. Lifting and overturning of large soil monoliths requires mobile cranes or other heavy lifting equipment. Dugas et al. (1985) used a single 36 Mg capacity crane to lift and overturn a 1.5-m x 2.0-m x 2.68-m deep monolith. Brown et al. (1974) lifted their 3-m^2 x 1.5-m deep monoliths from the ground with a crane of unspecified capacity and then rolled the tanks over on the soil surface. Two cranes of 27 Mg capacity or greater were used to lift and overturn the 3.0-m square x 2.3-m deep soil monoliths for the Bushland lysimeters. (Schneider et al., 1988). To prevent damage to the soil tanks, these monoliths were suspended by the cranes and overturned in the air in two, separate 90-degree rotations. The requirement for the heavy cranes may be a limitation if large, monolithic lysimeters are being installed at remote locations. Also, the large mass of the monoliths (30 Mg or greater) require special attachments and lifting rigging to prevent damage to the monolith tanks.

Enclosure Tank

Enclosure tank design for monolithic weighing lysimeters is essentially the same as for back-filled lysimeters. Basic requirements are adequate strength to withstand outside soil pressure and sufficient space for research equipment and personnel. If a high water table is possible, an underground drainage system around the perimeter of the tank is needed to prevent hydrostatic forces on the tank. Electric power for equipment and instrumentation and telephone service for data transmission are also desirable. Minimizing excavation around the enclosure tank can be more critical than with back-filled lysimeters. Plant growth in the back-filled area may not be representative of either the lysimeter or the undisturbed soil around the lysimeter. For example, the excavation for the enclosure tanks of the Bushland lysimeters (Marek et al., 1988) was only about 0.4-m larger than the tank dimensions. Yet, under water stressed conditions, plant growth in the narrow band of excavated soil is more vigorous than in the lysimeter or surrounding field. Minimum excavation requires vertical-walled pits and observance of excavation safety regulations.

Monolithic Versus Back-filled Lysimeters

Because of their higher initial cost and complex installation, monolithic lysimeters have generally been used only to preserve existing vegetation and soil properties that would be destroyed by excavation and backfilling. When considering the overall cost of collecting accurate evapotranspiration data; however, monolithic lysimeters may be competitive with back-filled lysimeters for a wider range of conditions. Quality installation of back-filled lysimeter requires precise excavation of soil layers, storage of the individual layers of soil and careful backfilling of each soil layer. These are time-consuming processes requiring considerable skilled labor. Modern monolith collection methods and the availability of high-capacity mobile cranes make the acquisition of a large monolith considerably easier than in the past. Thus, the time and expense for excavating and reconstructing a large soil block may be nearly as large as that required for collecting a similar-sized monolilth.

The time for stabilizing soil properties and for establishing native grass or trees may also add considerably to the overall expense of data collected with a back-filled lysimeter. Grebet and Cuenca (1991) show the effect of changing soil water properties for three years in a back-filled lysimeter at Pergamino, Argentina. During the first year of lysimeter operation, measured cumulative evapotranspiration was 35% higher than the predicted value. Not until the third corn crop in the lysimeter were the measured and predicted values of evapotranspiration similar. Thus, they show the loss of two scientist years and the expense of operating the lysimeter for two years before "reliable" evapotranspiration data were obtained.

Conclusions

Monolithic lysimeters preserve existing vegetation and soil properties that can be destroyed by excavation and back-filling. Quality data can usually be collected during the first year of operation whereas for back-filled lysimeters, several years may be lost while reestablishing soil properties and vegetation. Procedures for collecting large monoliths and constructing monolithic lysimeters are well

developed and have been documented by several researchers. Square, rectangular and circular monoliths have been collected with surface areas as large as 12.7 m^2 and depths as deep as 2.7 m. Monoliths have been collected in most types of soils, but the available methods are best for structured silt and clay soils.

Appendix. References

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